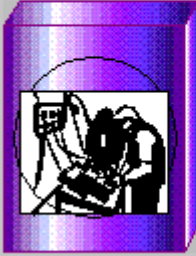


Chapter 9 AUTOMATION

9 Automation



Author: Colin G. Drury

Quote: "Far from reducing the importance of human factors, automation makes it even more vital to integrate the human operator with the automated system at all stages of the design process."

INTRODUCTION

There are many levels and types of automation. Some familiar physical functions, such as temperature control, are completely automated. That is, they require no human input other than specifying a desired setpoint. A common example is our home thermostat; set the desired temperature and the automation does the rest. In other situations, such as automobile engine control systems, automation converts continuous human input (the accelerator position) into system output (engine speed and transmission settings).

There are a number of definitions of automation that can apply to aviation maintenance. In this chapter, we will follow Wiener's [1](#) definition of cockpit automation, changed slightly to be appropriate for aviation maintenance. Automation means that "...some tasks or portions of tasks [normally] performed by the human [[AMT](#)] can be assigned to machinery" or computers. Thus, automation refers to any system in which the human worker is supported by mechanized or computerized components.

The term *automation* is usually confined to job assistance that has some degree of autonomous control. Examples range from automated self-checking routines in computers, to [CNC](#) machine tools in component shops, to mobile robots for lap-spice eddy current inspection.

As with most technological innovations, automation offers advantages and disadvantages. Automation can increase a task's repeatability (improving quality), reduce the level of required skill (lowering costs), and remove people from dangerous environments (enhancing safety). Automation can also be inflexible, can become rapidly obsolete, and may hide its internal operation from users, resulting in unexpected outcomes. Excessive or poorly-designed automation can lead to complacency among workers. Why worry about being conscientious when we know the automation will find any problems?

The bottom line in aviation maintenance (and elsewhere) is that automation can be very good for the bottom line. Appropriately designed and implemented automation will continue to be a central strategy for enhancing competitiveness. The danger is that over-optimism about automation's capabilities and the single-minded desire to eliminate direct labor can thwart appropriate and successful automation. Such organizational issues are as important to successfully introducing automation as the hardware and software components.

In this chapter, we explore automation as it applies to aviation maintenance. We examine

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fundamental concepts related to automation and discuss both advantages and disadvantages.

BACKGROUND

Automation is an old concept. Its roots are found in mechanization aimed at enhancing human muscle power. Advances in electronics, software, and materials have enhanced human control capabilities. Certain types of automation can aid human reasoning. The progress of automation can be traced in many domains. In the manufacturing domain, machinery has progressed from pedal lathes, to power lathes, to lathes with simple programs, e.g., screw-cutting, to computer numerically controlled lathes. Office work has advanced from pens, to typewriters, to word processors.

In aviation, cockpit and air traffic control automation has gradually improved until most flight activities are possible without direct human control, although human pilots remain an integral part of the system. In aircraft maintenance and inspection, much of the mechanization and automation that has occurred relates to paperwork, e.g., job control and scheduling, and to testing and troubleshooting aircraft components, e.g., avionics built-in-test systems or [BITEs](#). Most component shop activities rely on more traditional mechanization.

Information systems provide end users with great quantities of data. Which data are actually usable remains the focus of continuous debate.² However, no one questions that information automation provides information handling and processing capabilities far exceeding any level possible with manual systems.³ Examples include the following:

- Devising maintenance schedules that optimally package maintenance tasks into hangar visits³
- Job control and task scheduling for maintenance visits³
- Delivery of up-to-date job card information to [AMTs](#)
- Using bar codes to automatically capture data from inspectors' non-routine reports (NRRs)
- Presenting job card information to inspectors using hand-held computers⁴
- Pen-based computer systems for [FAA](#) inspectors (see [Figure 9-1](#))⁵
- Computer-assisted tracking of spare parts from repair organizations or parts vendors.

The US Air Force integrated many of these elements in the Integrated Maintenance Information System (IMIS).² In IMIS, a portable computer allows an [AMT](#) to access the maintenance history for an aircraft. It interfaces with built-in test equipment on an aircraft. Direct evaluations of this system against traditional (manual) systems show that it speeds up maintenance tasks and produces fewer diagnostic errors.²

[BITE](#) evaluates on-board components continuously or when queried. A typical BITE uses sensors within the component and employs test logic based on possible system failure modes. The [AMT](#) receives information through an interface that has progressed from an early analog-based display, through digital displays, to computer-driven, graphical interfaces.⁶ For an example of a BITE user interface, see [Figure 9-2](#).

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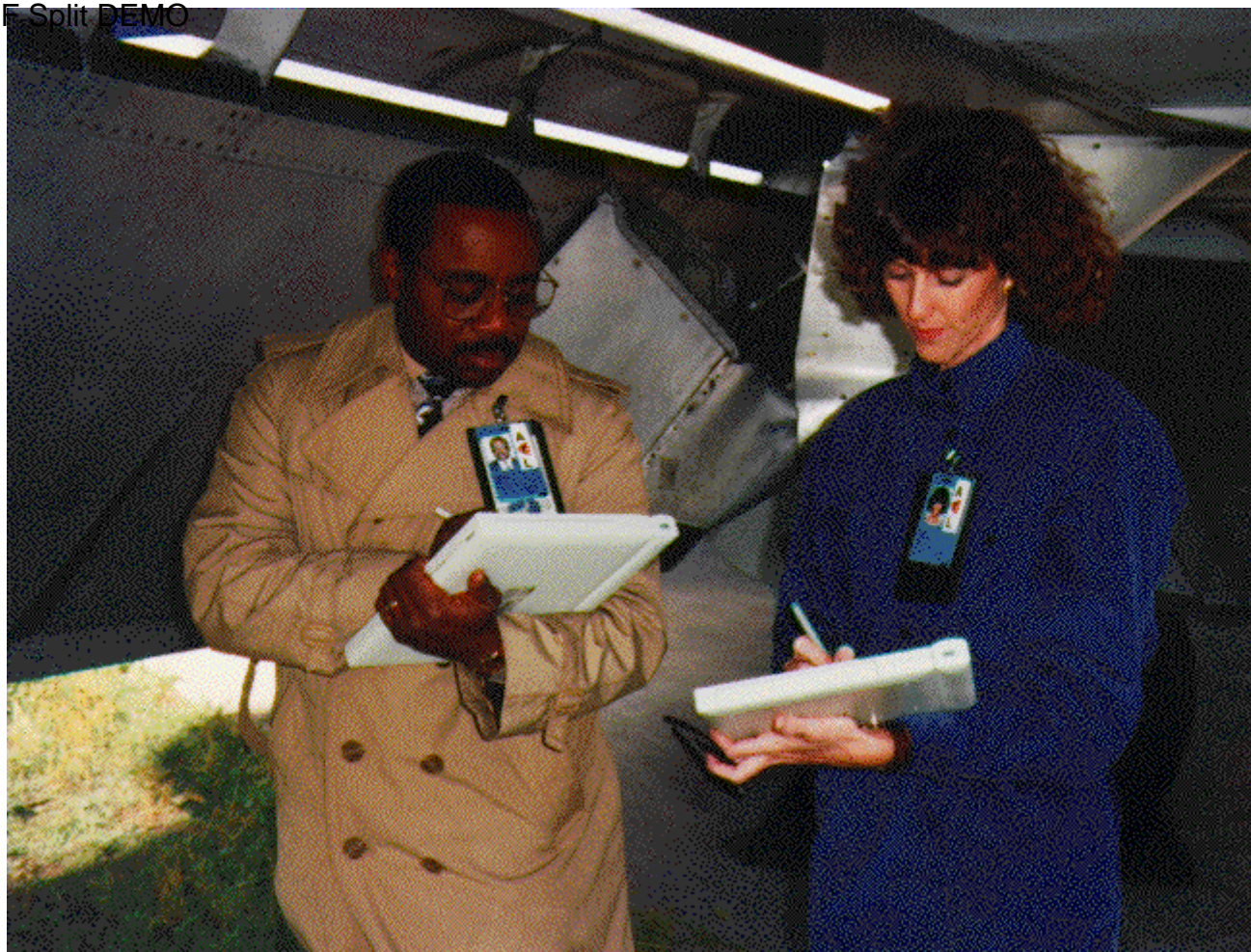


Figure 9-1. Pen-based computer systems for FAA Inspectors

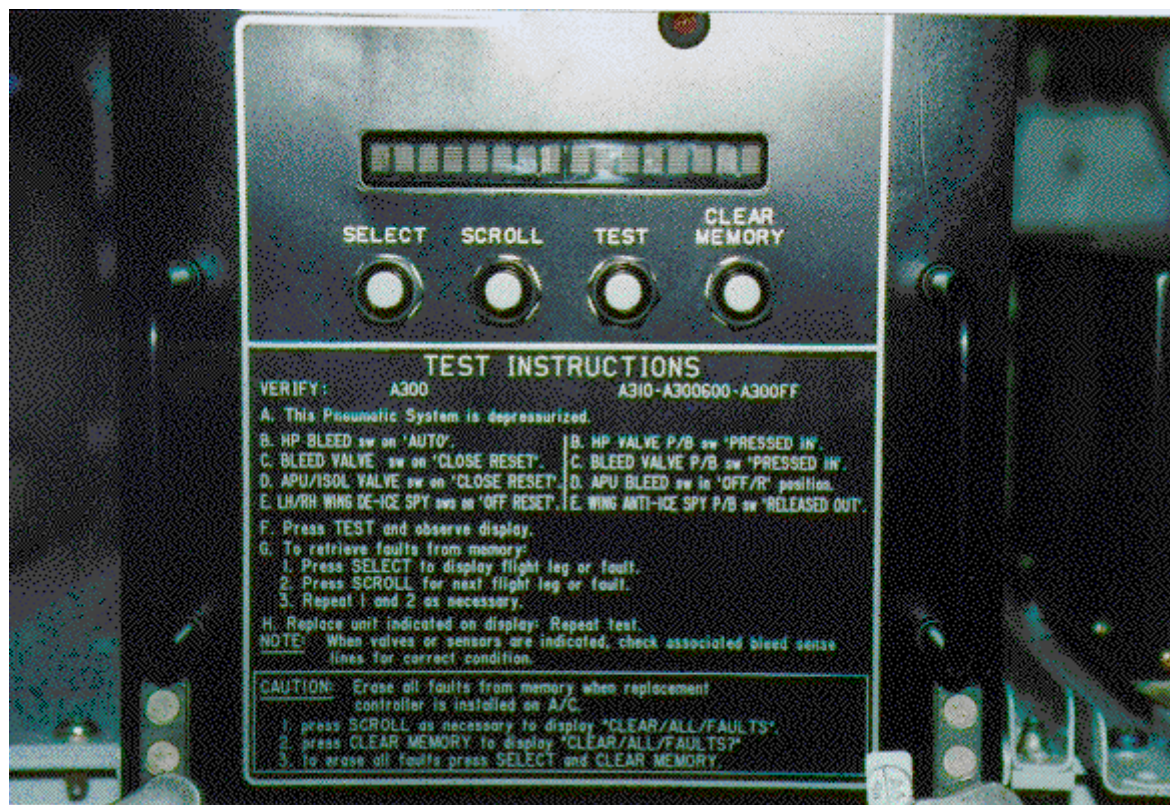


Figure 9-2. A modern BITE user interface (Courtesy of Delta Air Lines)

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Recently, individual [BITE](#) systems have been integrated into central maintenance computers (CMCs). These systems can consolidate fault reports from separate BITE systems and present a more comprehensive picture of an aircraft's condition. With higher levels of integration, onboard maintenance systems (OMS) diagnose the status of individual components, specify which need to be removed, and verify the replacement's functional capability.[6](#)

Automatic telemetry is used to acquire real-time data on specific aircraft components. Turbine engine performance data are routinely transmitted to ground stations via telemetry and then relayed to central analysis facilities to identify incipient component failures and to replace components before they cause problems.

Each new level of automation is hailed for reducing the shortcomings of previous levels, particularly in terms of increased reliability, better interface design, and eliminating false indications. This evolution will continue. However, not all attempts to automate produce positive results. The baggage-handling system troubles at Denver International Airport[7](#) show how total automation may not be the best solution. Recent incidents related to cockpit automation demonstrate some common, well-known pitfalls of automation.[8,9](#) Our challenge is to provide appropriate automation that maximizes its positive features while avoiding its disadvantages.[10,11](#)

ISSUES AND PROBLEMS

Automation does not necessarily eliminate job-related problems. In fact, studies of cockpit automation found that the locus of perception and performance problems simply shifts elsewhere.[12](#) The reality is that both automation and its lack can cause performance problems.[13](#)

Lack of Automation

Lack of automation can be the root cause of conflicts in scheduling maintenance tasks that must be performed in close proximity or that require the same resources. Lack of automation can lead to unnecessary removal of avionics equipment due to misdiagnosis of failures. Finally, lack of automation can lead to delays while [AMTs](#) consult documents, such as paper maintenance manuals, unavailable on the work site.

Poorly-Designed Automation

Poorly-designed automation can easily cause problems as severe as those resulting from the lack of automation. There are many hallmarks of poor automation design. One sign of poor design is excessive rigidity. An example of this characteristic is the failure of job scheduling automation that is incapable of quick re-scheduling in response to maintenance and inspection results.

Automated equipment may not be programmed to deal with unusual or combined failure modes in avionics diagnostics. There is also the problem of workers not knowing what the automated system is doing, or why. One author calls such lack of transparency the "veil of automation." It has been more of an issue in flight operations than maintenance.[14](#) In recent incidents, pilots were misled by the flight control computer, resulting in near accidents and accidents.[15](#)

Inappropriate Automation

Certain work functions or tasks are more appropriate candidates for automation than others. There is an ample human factors research base that can help identify which work-related functions, or parts of functions, are best performed by human workers and which are perhaps better allocated to automation. Unfortunately, many designers proceed from false assumptions regarding which tasks

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humans can or should perform. The tendency is to automate all tasks with even the least bit of cognitive challenge, thus relegating human workers to only the most mundane and uninteresting jobs. For a more detailed discussion of this topic, see [Function Allocation](#) in the CONCEPTS section.

Poorly-Implemented Automation

Problems of automation are not inherent in the concept of automation, but in its execution. Too often, little consideration is given to integrating human and computer tasks. This results in workers being either grossly over- or under-worked. Human perceptual and functional limitations are often not considered during human-automation interface design. Automation does not reduce the importance of human factors. Instead, it makes more vital the integration of human workers with automated systems at all stages of the design process.

REGULATORY REQUIREMENTS

There is no general regulatory guidance related to automation. However, for tasks in aircraft inspection and maintenance like Airworthiness Directive notices, exact methods to be used are detailed in service bulletins, maintenance manuals, etc. In these cases, check automation alternatives with regulatory authorities and manufacturers.

CONCEPTS

The process of choosing automation is often seen as making selections from an array of devices provided by manufacturers or developed in-house. This perception does not address the fundamental question of what **should** be automated; it merely shows what **can** be automated. Industry abounds with failed automation systems that either gather dust or continue to frustrate users. To avoid these problems, we need to consider appropriate automation. The concepts discussed below relate to fundamental ideas about identifying which functions should-and should not-be automated.

Function Allocation

To decide what may be appropriately automated, we first identify the functions a system has to perform. Functions are logically derived from a description of what the system must do. Functions specify **what** must be done, not **how**. Designing automation then becomes the task of allocating functions to available resources: to a person, to a machine, or to some combination of persons and machines.

The end result of this process is to automate only those functions that machines perform uniquely well, retaining people to perform functions for which humans are best suited. Such function allocation has been central to human factors since the discipline's inception.[15,16,17,18](#) There should be no pre-determined favoring of either automated or manual operation, just a willingness to let facts define function allocation.

Human-Centered Automation

Automation must address integrating functions into jobs. It is poor policy to automate every function possible, allocating to a person only "left-over functions."[19](#) Likewise, it is ineffective to allocate functions to people without considering job design issues. These aspects are dealt with more fully in [Chapter 6](#).

The underlying automation philosophy should be to allocate functions from the person outwards (human-centered design), rather than from the automation inwards (mechanical design). Systems in

which people are fully integrated by design maximizes long-term system effectiveness.[20](#)

Islands of Automation

We discuss the distinction between top-down and bottom-up design in [Chapter 1](#). In bottom-up design, the tendency is to focus on a particular device or technology and to try to find a use for it in the maintenance process. Bottom-up designs tend to be less effective than top-down designs. It is very difficult to identify, much less integrate, overall system goals in a bottom-up process. With automation, the temptation is quite strong to proceed with bottom-up design.

In maintenance, automation tends to focus on gadgets. Because of their training and inherent affinity for equipment, **AMTs** and managers are attracted to new gadgets. When automation proceeds without considering the overall maintenance process, only individual tasks become automated. The lack of an integrated framework for automation leads to automated tasks being known as "islands of automation."

Levels of Automation

Automation is often thought of as an all-or-nothing proposition. In the real world, choice is rarely between fully-automated and fully-manual ways of doing something. Existing commercial technology provides a number of levels of automation. We give four levels here, although many more are possible:[21](#)

- Fully manual - A person is responsible for the whole function, possibly aided by simple hand tools, such as torquing bolts
- Supervisory - A person is responsible for high-level goals, but a computer or machine controls low-level actions, such as setting and maintaining a constant temperature for curing composites. This concept is also known as *hybrid automation*
- Fully automatic - A machine, usually with an embedded computer, performs the entire function, for example power-on self test of computers

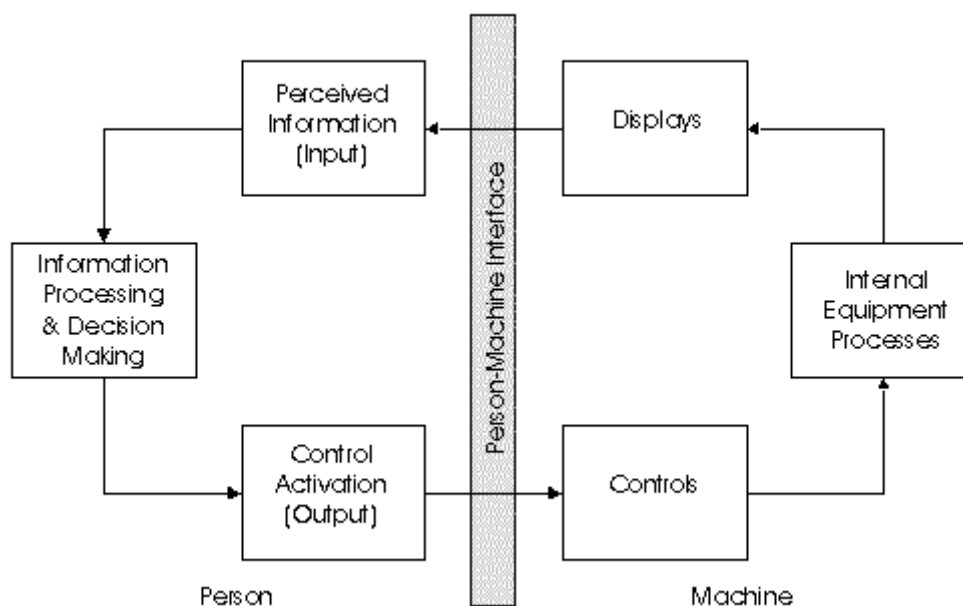


Figure 9-3. General diagram of a person-machine system

- Flexible allocation - Both people and machines can perform the function, with the choice being

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made when the function is invoked, e.g., autopilot in flight operations. With a flexible system, the decision is reversible, that is, you can always select or de-select automatic features, such as the speed control on a car.

Each level is appropriate for different functions in each system. None is inherently superior.

Person-Machine System

The system perspective is introduced in [Chapter 1](#) of this *Guide*. In the field of human factors, nearly all aggregations of people, procedures, and electronic and mechanical elements are viewed as an interacting system. [Figure 9-3](#) shows Meister's representation of this concept.²² It is difficult to change one part of a system without affecting other parts. This is certainly true for the effects of automation: by changing the "machine" side, we also change requirements placed on the "person" side.

The decision to automate certain functions doesn't necessarily preclude parallel, non-automated forms of that function. Automated and manual systems often coexist and complement each other. Introducing a computer database in an office does not preclude using paper forms to collect raw data. However, once an automated database is introduced, redesigned data forms may make the process more efficient.

Indeed, automation is often beneficial because it forces changes in other system components - these changes are the true source of system improvements. Burri and Helander²³ show how redesigning an electronic package to be assembled by robots was so successful that robots were no longer needed. Purchasers of automated equipment should beware of automation manufacturers' savings estimates. Savings based on applying good design practices can be achieved without automation.

Physical Fidelity

Models and mockups are often rated or judged on their similarity to the real component or system they represent. This characteristic is known as "fidelity", a term used in the same sense as how closely recorded music resembles the original rendition. There are two types of fidelity we consider when we evaluate mockups -- physical and psychological. (See [Psychological Fidelity](#)) Physical fidelity refers to the look and feel of the mockup compared with the real thing.

An example of mockups with very high physical fidelity are flight deck simulators. They look and feel nearly identical to the flight deck in an aircraft. An example of a mockup with low physical fidelity is a piece of cardboard with pictures or drawings of test equipment controls attached to it.

Psychological Fidelity

Psychological fidelity refers to the ability of a mockup or simulator to evoke the same cognitive and psychological processes as the real equipment. For many purposes, such as certain levels of training, the psychological fidelity of a mockup is much more important than its physical fidelity. For example, certain types of computer-based instruction can evoke very real experiences and feelings without being physically similar to real-life conditions.

Skill Atrophy

A frequent justification for automating is to reduce the required skill level for a particular task,²⁴ particularly when the available pool of workers is limited relative to these skills. A common example is automatic change calculations in cash registers. By eliminating the requirement that cashiers be able to calculate change, retail establishments draw from a larger pool of potential workers. However, when a skill is not practiced regularly, it may be unavailable when needed, in this case, when the cash register fails.

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In aviation maintenance, there are ample skill levels in the available [AMT](#) pool. The effect of automating tasks is to cause skills not used to atrophy. How many of us can still calculate a square root manually?

Skill atrophy is well understood in the cockpit domain. Modern aircraft are capable of automatically taking off, of making in-route navigational corrections, and of landing. Since pilots must maintain high skill levels for these tasks, they are allowed (in some cases, required) to operate their aircraft manually when weather conditions permit. The same consideration applies to deciding which parts of maintenance tasks to automate. When skills are lost, they cannot be regained instantly.

Workload

Workload was discussed in [Chapter 1](#). It is difficult objectively to measure certain types of workload, e.g., mental workload. This is important when considering automation because reducing workload is a primary reason for automating tasks. It is a common notion that automation is synonymous with reduced workload. In certain industries, automation reduces workers' physical workload by simply taking over tasks previously performed manually.

Automation does not necessarily reduce workload. In the [BACKGROUND](#) section, we noted that cockpit automation is advanced to the point that there is often no *technical* reason for human intervention. Theoretically, then, automation should drastically reduce the flight crew's workload. However, cockpit automation that is improperly integrated into the flight crew's job tasks actually increases workload.[25](#)

Automation can increase workload in many ways. One of the most common is to introduce automation, but also retain the manual elements. If workers manually enter data on paper forms to back up data entered into automated systems, their workload has increased beyond what it was for the manual system.

METHODS

A number of standard human factors methods apply to evaluating and designing automation for aviation maintenance. While we don't expect most readers of the *Guide* to actually design automated systems, knowing the proper design process will provide a solid basis for selection, evaluation, and other reasonable management tasks. Top-down design, the most general method, applies to all levels of system design, including automation.

We recommend top-down design as a first step for most automation-related design activities. Once overall design goals are established and system functions are allocated, other methods can be used for tasks such as comparing various automation products or evaluating existing automated components.

Engineering Analysis

There are many different types of engineering analyses. Each engineering discipline, electrical, mechanical, etc., has a portfolio of different analytical techniques. Technical engineering analyses should be part of the process of determining tradeoffs among system criteria and of evaluating automation alternatives. Such analyses, strictly speaking, do not fall in the human factors domain, but they are helpful for determining if alternatives are feasible in a particular operational environment.

Engineering analysis should be a "gating" function for selecting automation alternatives. At some point during the design, evaluation, and selection process, all products or systems meeting minimum functional requirements should be subjected to engineering analysis, and no final selection should be made without it.

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Job Safety/Hazard Analysis

Job Hazard Analysis (JHA), described in Chapter 3, is the fundamental analysis technique for identifying potential safety problems associated with particular job functions or tasks. JHA includes equipment-related hazards. For the purpose of evaluating automation alternatives, JHA can be used with actual equipment mock-ups. JHA can also be used without any equipment present, as when examining accident and injury reports related to automation alternatives similar to those being proposed - even reports from outside the aviation maintenance field. JHA commonly is used to evaluate hazards associated with automated robots.

Mock-Up Evaluation

Evaluating prototypes, or mock-ups, is discussed in [Chapter 6](#). It allows users to interact with the human-machine interface of a complex automated system without actually building the system. Standard automation products can be evaluated by visiting vendor facilities. Mock-ups are more appropriate when the automation alternative will be custom built for a particular application or when it is composed of different products uniquely connected.

Mock-ups should be used in conjunction with an analytical technique such as task analysis, walk-through analysis, or job safety analysis. The validity of results obtained with mock-ups, prototypes, or simulations depends on physical and psychological fidelity, i.e., on how closely physical and psychological cues the mock-up provides resemble those obtained with actual equipment. Psychological fidelity is often more important than physical fidelity. (See the [CONCEPTS](#) section of this chapter).

There are presently a number of "rapid prototyping" tools available. These allow designers to build very realistic computer interfaces that can be used to test various automation concepts.

Site Visits

A site visit, while not uniquely a human factors method, is a quick, relatively inexpensive way to gather information about automation products. There are two types of site visits: to vendor facilities and to businesses with installed equipment. The purpose of a site visit is to see a product actually being used for its intended purpose. Either a vendor or a customer site visit is appropriate. Obviously vendor demonstration sites are designed to present products in the best light possible.

Visiting a customer site allows you to observe the equipment in a work environment. It should be possible to interview people who operate the equipment. To make the most of this opportunity, develop a structured checklist of issues to address during the visit and make every effort to speak with equipment operators -- not merely with the engineer who specified the equipment or the manager who purchased it.

Task Analysis

Task analysis ([Chapter 1](#)) is a common human factors technique applied to analysis, design, and evaluation activities. For automation, task analysis can determine precisely how users presently perform certain tasks and how they might perform with automated products or systems.

Top-Down Design

Top-down design, as discussed in [Chapters 1](#) and [2](#), has particular relevance to automation. Appropriate automation choices should flow from the system's explicit goals, not dependent on rapid, yet misleading comparisons between "new" automated and "old" manual alternatives. This maximizes the benefits of automation and avoids most unanticipated problems that arise when the

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new system reaches the hangar floor. The method has five steps based on the work of Meister,[22](#) Price, et al.,[17](#) and Clegg, et al.[26](#)

Step 1: Choose System Criteria (Goals)

Distinctions between a good and a poor function allocation are not immediately obvious. For example, an automated device with higher initial cost and training requirements may improve throughput and decrease error rates. To make sensible choices, criteria for a good solution should be developed first. If we do not, there is a danger of bias, of selecting criteria making our favorite solution look good.

Step 2: Define System Functions

To meet overall performance goals, a system must perform specific functions. These functions can be identified either by logically breaking down system goals into sub-goals or by observing the existing system and writing down each step's desired product without specifying how the product is achieved. An example of a function description is, "Remove dirt." Note that this describes only what must be done, not how or by whom. The description "Have cleaners wash aircraft" goes too far, since it specifies who performs the function (cleaners) and how (wash aircraft). Specifying too many details prevents consideration of other alternatives, including automation.

Step 3: Generate Alternative Function Allocations

Once system functions are defined, each function must be allocated to a person, to an automated component, or to some combination. The usual advice is to generate one manual and one automated solution for each function; however, better results are obtained by going beyond this level and defining four alternatives, each corresponding to one of the four allocation levels in the [CONCEPTS](#) section.

Step 4: Evaluate Alternatives

When there are four alternatives for each function and criteria to measure each one's fitness, alternatives can be formally evaluated. The other methods in this section can be used for such an evaluation.

Step 5: Function Integration and Redesign

At this point, the initial allocations must be reviewed and reassessed for between-function compatibility. This may lead to redesign, to new alternatives, or even to a finer split of functions in the effort to ensure an overall satisfactory solution. Although the first four steps in this procedure are presented as a rigid sequence, there is ample room to backtrack and iterate until finalizing the design.

User Interface Analysis

Nearly all automation and mechanization alternatives have some type of user interface. For many products, the user interface is a computer-based display. However, any product to be used by people must have a user interface. Evaluate the user interface for each alternative with one, or more, of the many usability checklists available from various sources.[27,28,29](#)

Other evaluation methods in this chapter also provide user interface evaluation information. For example, a walkthrough indicates whether particular controls and indications provide users with the information and control capability they need to do their jobs. In addition, a structured usability checklist ensures that the user interface complies with minimum human factors requirements.

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Walkthrough Evaluation

A walkthrough evaluation, described in [Chapter 1](#), consists of having a system's prospective user(s) perform (walk through) each step of a particular task or function. It is most applicable to highly-proceduralized functions or tasks. A walkthrough to evaluate automation alternatives should be conducted either on actual equipment or on a mock-up with relatively high physical fidelity. Since a walkthrough evaluation is performed in stop-action fashion, it allows ample time for observations, comments, and "what if" scenarios, as well as an opportunity to record the evaluation for later discussion.

READER TASKS

When a task is being redesigned or a purchase is contemplated, the degree of automation is a key factor. This is why many people at many levels need to participate in function allocation decisions. Fortunately, the basic method for allocating functions applies to all levels, from designing complex systems for maintenance information, such as the Integrated Maintenance Information System (IMIS), to choosing a new ultrasonic inspection device.

In all cases, the reader needs to list system functions, to develop criteria for what is "good" allocation, to generate alternative allocations for each function, to evaluate each allocation against the criteria, and then to choose a particular allocation. We provide guidance for top-down function allocation and for evaluating automation alternatives.

Function Allocation

Most function allocation methods are presented at the whole-system level, as are Meister's [22](#) defense systems and Sinclair's [30](#) factory production systems. Any function allocation method can be used at whatever level of generality the particular application requires. You might want to look at a single task such as inspecting an "O"-ring or at a large aggregation of activities such as performing a C- or D-check. Regardless of the level of generality, the material in the [GUIDELINES](#) section can be applied.

Evaluating Automation Alternatives

At some point in every automation process, decisions are made regarding which alternatives to choose. There is always a trivial possibility that there is only one automation product for a particular task. This situation is rare, given competition in the maintenance equipment business. A common maintenance management task is choosing among automation alternatives. This process need not rest on intuition, engineering judgment, or educated guesses - though we don't necessarily preclude these variables. The intent of the material in the [GUIDELINES](#) section is to quantify, as much as possible, the decision making process.

GUIDELINES

Function Allocation

The [five-step procedure](#) described in the METHODS section can be used whenever automation is considered. The function allocation method is shown schematically in [Figure 9-4](#).

Step 1: Choose Criteria (Goals)

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We cannot choose between alternative levels of automation unless we have explicit criteria for the choice. Suitable categories of criteria are provided in [Table 9-1](#).

Table 9-1. Examples of criteria categories

Effectiveness

- task scope
- error type/rate
- reliability
- weight/size where limiting (e.g., in restricted spaces)
- environmental characteristics

Efficiency

- speed/throughout
- initial cost
- running cost
- disposal cost for future systems

Human well-being

- safety
- health
- satisfaction

We can choose conflicting criteria, requiring compromises. For example, criteria requiring low initial cost and high throughput might be incompatible. Unless one criterion, such as errors or safety, is overriding, we need a scheme for combining criteria. This should be developed before selecting automation alternatives.

A common approach is a weighted-sum. Each criterion is given a weight and the product of criterion and weight measures an alternative. We do not recommend this approach; it is rarely necessary. A design team can make most decisions when alternatives are scored on each criterion, with results presented as a matrix. People excel in reaching shared decisions based upon multiple conflicting criteria, as when a family chooses a home in a new community. Design teams should exploit this human capability, rather than argue over weighting factors for criteria.

Choosing criteria based on categories in [Table 9-1](#) is appropriate in most cases, but there are two special cases:

1. By mandate, some functions cannot be completely automated
2. Some automation alternatives are immediately eliminated because of initial cost constraints.

Complete automation disallowed. Laws or regulations may prohibit complete automation of certain functions. For example, it is not possible to eliminate a human pilot from commercial aircraft. Company policy or labor agreements often forbid automation, as well. Some airlines only accept an inspector's original signature on paper as proof of job completion, though other means are technically feasible.

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In such cases, there is no need for criteria other than "meets legal requirements" or "meets company policy." However, many company policies are open to change if there is sufficient reason. Designers have missed innovation opportunities because of untested or mythical policies.

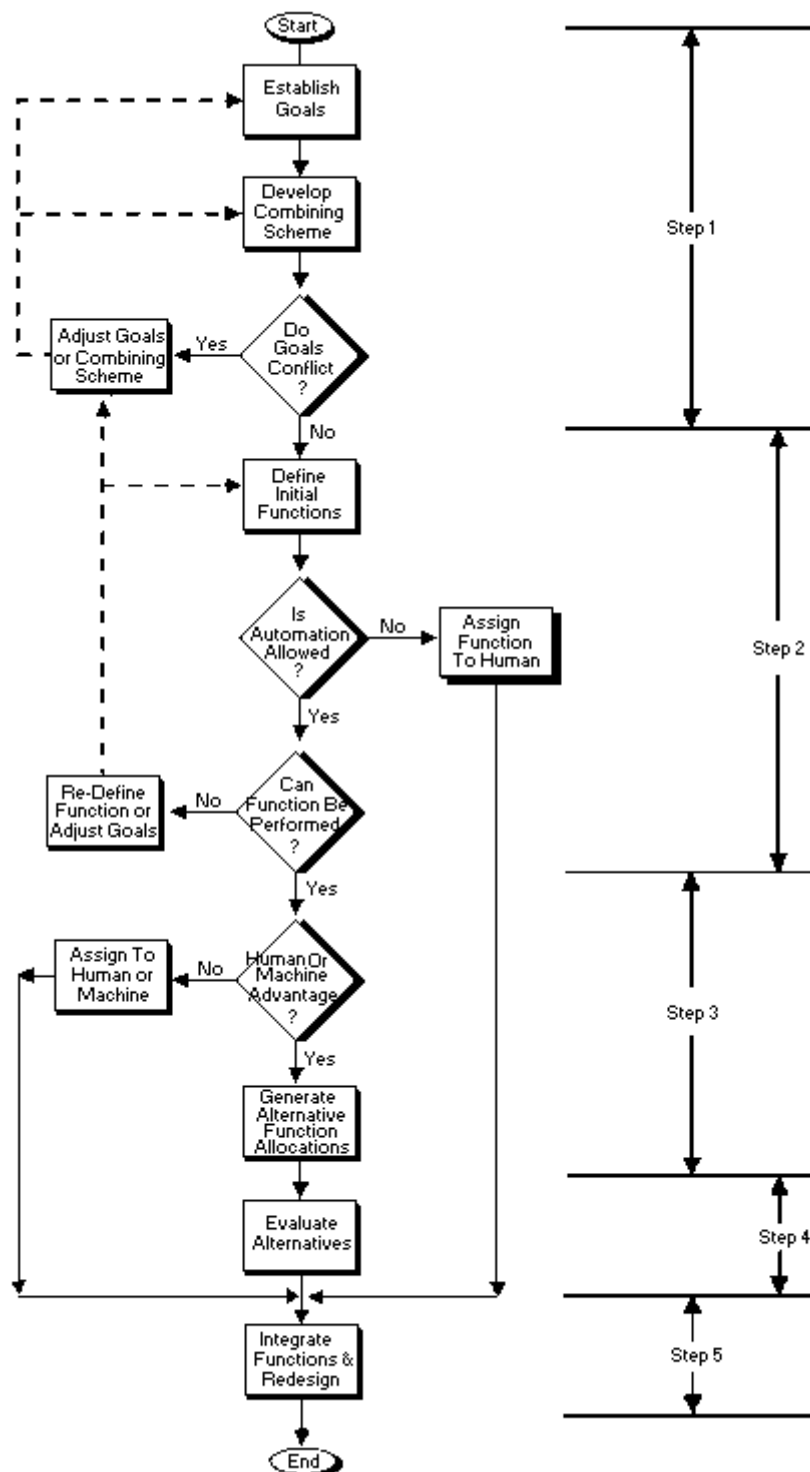


Figure 9-4. Function allocation process

Initial cost constraints. A common, often unfortunate criterion is that initial cost be minimized. A more beneficial criterion is minimized life-cycle cost. There are periods when organizational cash flow is problematic and, during such times, it is prudent to minimize new investments. However, rejecting an alternative with a life-cycle cost justification on grounds of initial cost does not

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maximize the organization's competitive posture. Generally, the initial costs of microelectronics-based automation decrease over time. This implies that organizations should move incrementally towards automation and reevaluate alternative function allocations frequently.

Step 2: Define System Functions

At the system level of initial design, functions tend to be general, indeed generic. As each system component is designed, associated tasks become more specific. Thus, if we analyze the control system for jobs that are currently done with job cards, specific functions might be "Present task steps to [AMT](#)" and "Record task step completion". The specific functions remain means-independent; they could be accomplished equally well with pencil-and-paper or a portable computer.

Perhaps the best way to illustrate separating a system into functions is with an example. The current job control card system has a number of functions; many have automation alternatives. To start the function definition process, begin with inputs and outputs to the whole system shown in [Table 9-2](#).

Table 9-2. Starting function definition

System:

Job Control Cards

Inputs:

Scheduled maintenance and inspection jobs

Task steps in each job

Estimated job time

Skilled AMTs

Output:

Jobs completed to correct standard

Data on job completion and findings

From this, we derive functions necessary to turn inputs into outputs. [Table 9-3](#) lists them in no particular order. The term "worker" in Table 9-3 describes all system participants, e.g., [AMTs](#), inspectors, managers, etc.

Table 9-3. Initial function list

Functions:

1. Control when each job is performed.
2. Record worker and aircraft data for each job.
3. Present information on task steps to worker.
4. Present required back-up information to worker.
5. Record completion of each job.

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6. Produce reports on findings for each job.

All these functions have a current allocation in the existing job card system. For example, presenting information on task steps is accomplished with a paper copy of task instructions (the job card) for each job. Job control is achieved by assigning that job card to an [AMT](#).

Functions can be defined as a verb (what is done) and a noun (what it is done to), although both parts may be phrases or have qualifiers. Function 6 is as follows:

<u>Produce</u>	<u>reports on findings</u>	<u>for each job</u>
verb	noun phrase	qualifier

The means of performing each function is deliberately omitted to leave function allocation free of biases from the existing system.

Step 3: Generate Alternative Function Allocations

Using the [four allocation levels](#) in the CONCEPTS section, we define four alternatives:

Alternative 1: Fully manual

Alternative 2: Supervisory/hybrid

Alternative 3: Fully automated

Alternative 4: Flexible allocation

Alternative 4 is simply using more than one alternative, with a means to switch during system operation.

Alternatives are often obvious when one is familiar with the existing system and with well-known automated alternatives. Such alternatives usually address pre-defined systems, not individual functions. Pre-defined alternatives may be less useful than those designed for each individual function.

Generating alternatives is a difficult, interesting part of the function allocation process. An existing system often provides one alternative, and others must be generated with available resources. Keeping up-to-date with developments reported in technical magazines can help, but ideas come from a variety of sources. Your pleasure reading of computer magazines or even *Popular Mechanics* can provide useful ideas. Many professional designers and engineers maintain a "tickler file" of ideas clipped from many sources which "may come in handy one day."

The aim of the process is to generate alternatives until there is at least one at each automation level for each function. However, do not generate alternatives when mandatory requirements like legal restrictions force a function to be allocated to one particular level.

Step 4: Evaluate alternatives

Once alternatives are generated, they must be evaluated to determine feasibility and effectiveness. For evaluation, we must know how each alternative rates on each criteria. Some data are simple to obtain, such as the initial cost of automation hardware. Other criteria may be difficult to quantify. What are potential error rates with new techniques? Are alternatives as flexible as the manufacturers claim? How safe are new systems in practice? Some methods to evaluate alternatives are described in the [METHODS](#) section.

Once ratings on each criterion are developed, apply the scheme for combining different criteria ([Step 1](#)) to obtain an evaluation of each alternative's "goodness" for each function.

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When humans and machines are compared directly, results are predictable.³¹ People are flexible and intelligent; machines are consistent and rigid. Elaborate tables list relative advantages of people and machines.³² While intellectually interesting, such tables are rarely used for function allocation because alternatives are rarely as clear-cut as unaided humans versus unaided machines. More typically, the search is for a hybrid system utilizing the best features of each potential "component."

People are not good at producing large forces, at applying the same force consistently over time, at performing rapid calculations, or at sensing ionizing radiation. However, people's skills at delicate manipulation, at inductive reasoning, at pattern recognition, and at producing intelligent behavior in unanticipated situations are extremely difficult to duplicate in metal and silicon. Real choices must be made in some areas, though. Does a mechanic need physical assistance to lift a 10 kg load? Should our computer use a handwriting recognition algorithm with 90% reliability or reproduce handwriting as a graphic for another person to read?

These choices are captured in [Figure 9-5](#), adapted from Price, et al.¹⁷ Any function can be represented by a point on a surface; its axes are criterion scores for humans and for machines in performing that function. We rule out assigning any particular function to people if its score falls in the area where human performance is unsatisfactory, i.e., U_{human} . Likewise, we rule out automation if its score falls in the area labeled U_{machine} . A function's score may fall in the U_{both} area where neither humans nor automation can support the function. This function must be redefined or the system's mission must be rethought.

Functions best performed by people should be allocated to humans. For functions both humans and machines perform equally well, flexible allocation is possible. People and machines are equally viable alternatives only for the functions in the diagonal area of [Figure 9-5](#). When a system is separated into its functions, choosing between alternatives for each function is not difficult.

A direct evaluation of alternatives from a related field is instructive. Hou, Lin and Drury³³ tested different function allocations for inspecting computer-generated circuit boards. These inspection functions are similar to aircraft inspection:

- Present board to inspector
- Search board for indications
- Decide on whether indication is beyond standard
- Respond by sending board to customer or to repair.

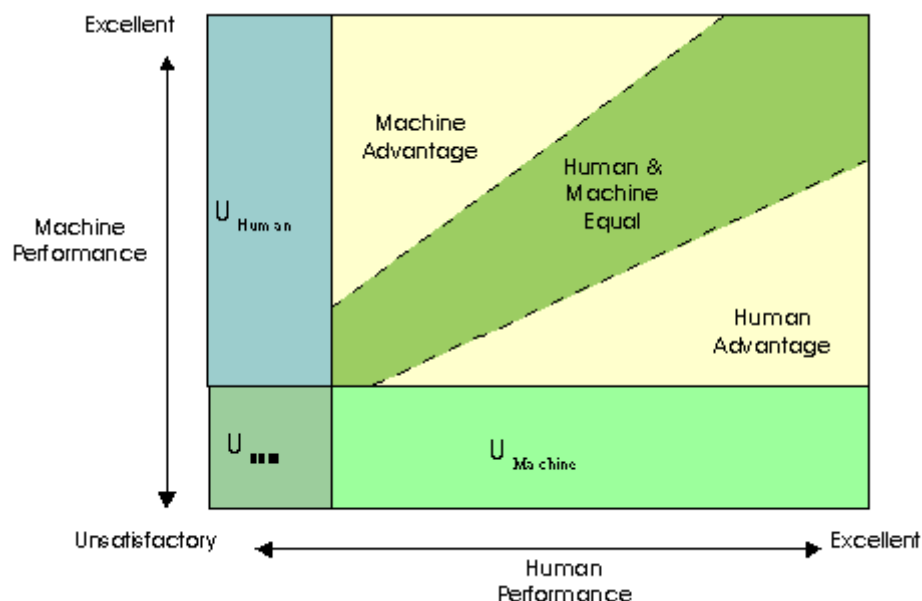


Figure 9-5. Function allocation decision surface

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"Present" and "Respond", simple mechanical functions best suited for a machine, were allocated to hardware. "Search" and "Decide" functions could be allocated to an inspector, a machine, or to both together. Since search is not typically well suited for human inspectors,[34](#) only five different allocations were compared. One used unaided inspectors, and two used unaided automation, either a template- matching or a neural net algorithm. Neural nets mimic certain human mental processes. The remaining two were hybrid systems: the machine searched and either an unaided inspector or an inspector/machine combination decided.

Each alternative was measured for inspection errors and speed. The hybrid systems were significantly better than either unaided inspectors or unaided automation. Although such direct evaluations are somewhat rare, the results show that hybrid systems using the best features of both automation and people can give superior results.

A note of caution on evaluation is appropriate. When your goal is to replace an existing alternative with a new one, use equivalent measures of the two alternatives. Do not compare the old system's well-known problems with the manufacturer's assurances about the new one. Either get a realistic appraisal of the new system from other users or compare the manufacturer's representation of the new system with the equivalent representation of the old system. Improvements and progress must be based on realism, not optimism.

Step 5: Function integration and redesign

When you find the best alternatives for each function, there is no guarantee that alternatives are compatible. One alternative may require compressed air as its power source; others require 220 [VAC](#) and 24 [VDC](#). Providing three power sources may be neither sensible nor possible. It is also possible that functions allocated to people are incompatible. If an [AMT](#) must have high strength to manipulate large components and be small enough to fit in a restrictive space, it may be difficult to find even one competent person with both attributes.

This final step ensures that all the automated and manual functions fit together into an effective system. It is often the case that automating certain steps (or entire functions) radically changes the complexion of the human-machine system. In some instances, this might require another analysis and design cycle to fully integrate human and automated elements.

In any case, assigning a function to human or automation is only the first step in actually implementing these elements. Other chapters in the *Guide* contain information that can be used to analyze, evaluate, and design the jobs, interfaces, workspaces, training systems, etc., that result from our functional allocation.

WHERE TO GET HELP

We are not aware of any organizations that deal exclusively with automation in the aviation maintenance environment. However, there are several groups that are actively working on automation projects that are maintenance related. The Airlines Electronic Engineering Committee of ARINC is presently working on the Portable Maintenance Access Terminal (PMAT), which is designed to load flight management software. This committee is probably a good starting point for inquiries related to maintenance automation.

ARINC

Airlines Electronic Engineering Committee

2551 Riva Road

Annapolis, MD 21401

A-PDF Split DEMO**Phone: (410) 266-4110****Fax: (410) 266-2047****Web: <http://www.arinc.com>**

It is not clear that the Air Transport Association has an active presence in aviation maintenance automation. However, the Engineering Department of the [ATA](#) is usually a good contact point for any type of technical question related to aviation.

Air Transport Association of America**Engineering Department****1301 Pennsylvania Ave., NW****Washington, DC 20004****Phone: (202) 626-4000****Fax: (202) 626-4081****E-mail: ata@air-transport.com****Web site: <http://www.air-transport.org>**

Within the Human Factors and Ergonomics Society (HFES), the Aerospace Systems Technical Group concerns itself with all human factors issues related to aviation, including those issues pertaining to maintenance. Since the composition of the Technical Groups changes each year, it is best to contact them through the HFES central office.

Human Factors and Ergonomics Society**Aerospace Systems Technical Group****PO Box 1369****Santa Monica, CA 90406****Phone: (310) 394-1811****Fax: (310) 394-2410****E-mail: HFES@compuserve.com****Web: <http://hfes.org>**

Another potential source of information regarding maintenance automation is the Civil Aeromedical Institute (CAMI). This organization deals with many cockpit and air traffic control (ATC) automation issues and might be able to steer maintenance people to the appropriate person or group.

Dr. Robert E. Blanchard**Director - Human Factors Laboratory****FAA Civil Aeromedical Institute****Box 25082, AAM-510****Oklahoma City, OK 73125****Phone: (405) 954-4082****Fax: (405) 646-6218**

FURTHER READING

The documents below contain information pertaining to automation. They may or may not have been referred to in the chapter. The citations are grouped under general topics to make finding particular information easy. Within each topic area, all references are arranged alphabetically.

Cockpit Automation

Casey, S.M. (1993). *Set phasers on stun-and other true tales of design, technology, and human error*, pp. 92-108. Santa Barbara, CA: Aegean Publishing Company.

A-PDF Split DEMO

Hawkins, F.H. (1987). *Human factors in flight*, pp. 248-251. Aldershot, UK: Gower Technical Publications.

Stinnett, T.A. (1989). Human factors in the super cockpit. In R.S. Jensen (Ed.), *Aviation psychology*, pp. 1-37. Brookfield, VT: Gower Publishing Company.

Wiener, E.L. (1988). Cockpit automation. In E. L. Wiener and D.C. Nagel (Eds.) *Human factors in Aviation* (Chapter 11). San Diego, CA: Academic Press.

Function Allocation

Jordan, N. (1990). Allocation of functions between man and machines in automated systems. In M. Venturino (Ed.), *Selected Readings in Human Factors*, pp. 55-59. Original work published in 1963. Santa Monica, CA: Human Factors and Ergonomics Society.

Kantowitz, B.H., and Sorkin, R.D. (1987). Allocation of functions. In G. Salvendy (Ed.), *Handbook of Human Factors*, pp. 355-369. New York, NY: John Wiley & Sons.

Human Performance

Parasuraman, R., and Mouloua, M. (Eds.) (1996). *Automation and human performance: Theory and practice*. Mahwah, NJ: Lawrence Erlbaum Associates.

EXAMPLE SCENARIOS

The scenario below represents typical automation-related tasks one can expect to encounter in the workplace. The purpose of including this scenario in the *Guide* is to demonstrate how the authors foresee the document being used. For each issue raised in the scenario, we describe how it can be resolved using information in the *Guide*. There is usually more than one way to approach these issues, so the responses given below represent only one path users of the *Guide* might take.

As a general rule, always start to look for information by using the Search function. There will be instances that you already know where required information is located. However, unless you frequently use specific sections of the *Guide*, you might miss information pertaining to the same issue located in more than one chapter. The Search will allow you to quickly search all chapters simultaneously.

In this chapter, we describe a multi-step process for designing and implementing automation. In this process, each step uses the output of previous steps. This section develops key steps in a single scenario, rather than going through steps in separate scenarios. This scenario parallels the [workcard](#) example in the GUIDELINES section of the chapter.

Scenario - Function Allocation

You see possible benefits of an ultrasonic delamination tester for tires used at other airlines. This device allows on-condition tire replacement, rather than fixed-life replacement. You would like to build such a system. Because your fleet has many tire sizes, you need a flexible system and nothing in your market survey seems entirely satisfactory.

This is a good time to try out the automation and function allocation ideas you read about recently. You would like to focus the design team on real issues of deciding how much automation is appropriate.

Each issue below moves through steps in the process. The answers from one step allow you to progress to the next.

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Issue 1

What are the criteria for good design?

Response

The first step in the function allocation process, as described in the [METHODS](#) and [GUIDELINES](#) sections, is to choose system criteria (goals). In effect, you are asking, "What must the system do for us to consider it successful?" Do you know what an ultrasonic delamination tester should do? Obviously, it should classify tires as "good", i.e., suitable for further use, or "bad", i.e., unfit for further use. Given this goal, which essentially aims to maintain high levels of flight safety, we can state two criteria immediately:

1. Should classify good tires as "good" while minimizing the number of costly false alarms.
2. Should classify bad tires as "bad" while minimizing the number of missed delaminations. These are even more costly, as they affect public safety.

Assuming that an ultrasonic system meets criteria, for example, of less than 5% false alarms and less than 0.01% missed delaminations, other criteria can be stated:

3. Minimize time required to process each tire.
4. Minimize training time for operators.
5. Minimize environmental and safety effects.
6. Minimize system maintenance requirements.

There are also cost criteria such as cost of acquisition, of operation, of maintenance, of disposal. Savings result from increased tire utilization:

7. Maximize lifecycle savings; conversely, minimize lifecycle costs.

Issue 2

List the functions of the tire testing system.

Response

We must define the proposed system's functions, using various processes. In this case, we assume that our design team conducted logical analysis of functions **any** tire testing system must to support. A tire must be mounted on the tester, tested, and dismounted. A decision regarding its condition must be made. Thus, there are the following functions:

Function 1: Set up the system for the correct tire size.

Function 2: Mount the tire.

Function 3: Run the system-control speed of rotation, fluid flow, data recording, etc.

Function 4: Interpret data to make a decision.

Function 5: Dismount the tire.

Function 6: Shut down the system.

Other functions include troubleshooting, maintenance, and final disposal, but we confine ourselves to operational use. Note that we have not said which functions are manual, which are automated. We should not assume that mounting the tire is a manual process; it might be automatic. It might not be

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necessary to mount a tire once the design is more fully developed.

Issue 3

Generate alternatives for each function.

Response

In the [GUIDELINES](#) section, we suggest generating at least four alternatives for each function:

- Fully manual
- Supervisory/hybrid
- Fully automated
- Flexible allocation.

We illustrate this for the first function: setting up the system for the correct tire size.

Assume that ultrasonic technology requires the tire be rotated while an ultrasonic scanner moves across the tire, providing a "map" of the whole tire carcass. The tire's diameter, width, and material need to be set to allow correct positioning of the tire and of the ultrasonic transmitter and receiver. The design team should discuss the requirements and develop sensible alternatives for each of the four categories. Examples include the following:

Fully Manual: The technician reads the tire size and sets wheel diameter and probe positions, using calibrated scales. A printed look-up table provides correct settings for each tire type in the fleet.

Supervisory/hybrid: The technician selects the tire type from a menu in the control computer. It then displays required settings on a visual display terminal (VDT). The operator makes settings manually, as for the fully manual alternative.

Fully Automated: As the tire is mounted, a computer reads a bar code inside the carcass and makes all settings with stepper motors. When settings are verified, the computer releases the system from a set-up mode so it can be run.

Flexible Allocation: Both fully automated and fully manual modes are possible by switching between them. This is used when sensors fail, when calibrating the system, and for operator training.

Further Issues

It is not possible to proceed to subsequent design steps without actual design data, requirements, and costs. We encourage readers to repeat [Issue 3](#) to practice generating alternatives for other functions.

REFERENCES

The following documents were referenced by number in the chapter:

1. Wiener, E.L. (1988). Cockpit automation. In E.L. Wiener and D.C. Nagel (Eds.) *Human factors in aviation* (Chapter 11). San Diego, CA: Academic Press.
2. Johnson, R.C. (1990). [An integrated maintenance information system \(IMIS\): An update](#). *Final Report-Second Federal Aviation Administration Meeting on Human Factors Issues in Aircraft Maintenance and Inspection: Information Exchange and Communications*, pp. 141-150. Washington

A-PDF Split DEMO
 DC:FAA/OAM.

3. Goldsby, R.P. (1992). [Effects of automation in maintenance](#). In *Proceedings of the Fifth FAA Meeting on Human Factors Issues in Aircraft Maintenance and Inspection*, pp. 103-123. Falls Church, VA: BioTechnology, Inc.
4. Patel, S., Drury, C.G., and Prabhu, P. (1993). Design and usability evaluation of work control documentation. In *Proceedings of the 37th Annual Meeting of the Human Factors and Ergonomics Society*, pp. 1156-1160. Santa Monica, CA: Human Factors and Ergonomics Society.
5. Layton, C.F., and Johnson, W.B. (1993). Job performance aids for flight standards service. In *Proceedings of the 37th Annual Meeting of the Human Factors and Ergonomics Society*, pp. 26-29. Santa Monica, CA: Human Factors and Ergonomics Society.
6. Hessburg, J. (1992). [Human factors considerations on the 777 on-board maintenance system design](#). In *Proceedings of the Sixth FAA Meeting on Human Factors Issues in Aircraft Maintenance and Inspection Maintenance 2000*, pp. 77-91. Alexandria, VA: BioTechnology, Inc.
7. Woodbury, R. (1994). The bag stops here. Are the luggage-delivery glitches in Denver's long-delayed airport fixable anytime soon? *Time*, May 16.
8. Sparaco, P. (1994). Human factors cited in French A320 crash. *Aviation Week & Space Technology*, January 16, p. 30.
9. Sparaco, P. (1994). A330 crash to spur changes at Airbus. *Aviation Week & Space Technology*, August 8, pp. 20-22.
10. Hughes, D., Dornheim, M.A., Sparaco, P., Phillips, E.H., and Scott, W.B. (1995). Automated cockpits special report, Part 1. *Aviation Week & Space Technology*, 142(5), pp. 52-65.
11. Hughes, D., North, D.M., Scott, W.B., Nordnall, B.D., and Phillips, E.H. (1995). Automated cockpits special report, Part 2. *Aviation Week & Space Technology*, 142(6), pp. 48-57.
12. Wiener, E.L., and Curry, R.E. (1980). Flight deck automation: Promises and problems. *Ergonomics*, 23, 995-1011.
13. Parasuraman, R., and Mouloua, M. (Eds.) (1996). *Automation and human performance: Theory and applications*. Mahwah, NJ: Lawrence Erlbaum Associates.
14. Edwards, E. (1988). Introductory overview. In E. L. Wiener (Ed.) *Human Factors in Aviation*. San Diego, CA: Academic Press.
15. Wiener, E.L. (1984). Vigilance and inspection. In J.S. Warm (Ed.), *Sustained Attention in Human Performance*, pp. 207-245. New York, NY: John Wiley & Sons.
16. Fitts, P.M. (1951). *Human engineering for an effective air navigation and traffic control system*. Washington, DC: National Research Council.
17. Price, H.E., Maisano, R.E., and Van Cott, H.P. (1982). *The allocation of functions in man-machine systems: A perspective and literature review*. (NUREG-CR-2623) Oak Ridge, TN: Oak Ridge National Laboratories.
18. Drury, C.G. (1994). Function allocation in manufacturing. In S.A. Robertston (Ed.), *Contemporary Ergonomics 1994-Proceedings of the Ergonomics Society's 1994 Annual Conference*,

A-PDF Split DEMO
pp. 2-16. UK: University of Warwick.

19. Bainbridge, L. (1990). Ironies of automation. *Automatica*, 19, pp. 775-779.
20. Brödner, P. (1994). Design of work and technology. In G. Salvendy and W. Karwowski (Eds.), *Design of Work and Development of Personnel in Advanced Manufacturing*, pp. 125-157. New York, NY: John Wiley & Sons.
21. Sheridan, T.B. (1988). Task allocation and supervisory control. In M. Helander (Ed.), *Handbook of Human-Computer Interaction*, 8, Amsterdam, NE: Elsevier.
22. Meister, D. (1971). *Human factors theory and practice*. New York, NY: John Wiley & Sons.
23. Burri, G., and Helander, M.G. (in press). Cost effectiveness of ergonomics improvements in the electronics industry. *International Journal of Industrial Ergonomics*.
24. Norman, D.A. (1988). *The design of everyday things*. New York, NY: Doubleday.
25. Hoover, G.W. (1992). Stop saturating pilots with alphanumeric hieroglyphics. *Aviation Week & Space Technology*, June 15, pp. 98-99.
26. Clegg, C., Ravden, S., Corbett, M., and Johnson, G. (1989). Allocating functions in computer integrated manufacturing: A review and a new method. *Behavior and Information Technology*, 8, pp. 175-190.
27. Dumas, J.S., and Redish, J.C. (1993). *A practical guide to usability testing*. Norwood, NJ: Ablex.
28. Rubin, J. (1994). *Handbook of usability testing*. New York, NY: John Wiley & Sons.
29. Mayhew, D.J. (1992). *Principles and guidelines in software user interface design*. Englewood Cliffs, NJ: Prentice-Hall.
30. Sinclair, M.A. (1993). Human factors, design for manufacturability and the computer-integrated manufacturing enterprise. In M. Helander and M. Nagamachi (Eds.), *Design for Manufacturability*, pp. 127-146. London, UK: Taylor & Francis.
31. Jordan, N. (1963). Allocation of function between man and machines in automated systems. *Journal of Applied Psychology*, 47, pp. 161-165.
32. Fitts, P.M. (1962). Functions of man in complex systems. *Aerospace Engineering*, pp. 34-39.
33. Hou, T.S., Lin, L., and Drury, C.G. (1993). An empirical study of hybrid inspection systems and allocation of inspection function. *International Journal of Human Factors in Manufacturing*, 3, pp. 351-367.
34. Drury, C.G., and Prabhu, P. (1994). Information requirements of aircraft inspection: Framework and analysis, submitted to *International Journal of Man-Machine Studies*.